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(54) Title: FLUORENE COPOLYMERS AND DEVICES MADE THEREFROM

(57) Abstract

This invention relates to: (a) fluorene copolymers comprising at least 10 percent (by residual monomeric units) of 9–substituted and/or 9,9–disubstituted fluorene moieties and at least two other monomeric units containing delocalized p–electrons, (b) polymer blends comprising at least 10 weight percent of a copolymer specified in (a), and (c) electronic devices (such as polymer light emitting diodes) containing one or more films derived from these copolymers.

FLUORENE COPOLYMERS AND DEVICES MADE THEREFROM

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This invention relates to fluorene copolymers, polymer blends comprising such copolymers, and electronic devices (such as polymer light emitting diodes) containing one or more films derived from these copolymers.

Conjugated polymers may exhibit the optical and electronic properties of inorganic semiconductors because of the presence of delocalized p-electrons. Poly(9,9-disubstituted-fluorene-2,7-diyls) constitute a family of semiconducting polymers with advantageous features. Their aromatic backbone is resistant to chemical and photochemical degradation; the biphenylene unit of each fluorene monomer is locked into a planar-like configuration by the C9 atom; substituents on C9 may be chosen to modify physical and chemical properties without introducing torsional strain between adjacent fluorene units which would otherwise be disruptive to delocalization of the p-system. Indeed, poly(9,9-di-n-octylfluorene-2,7-diyl) of U.S. Patent 5,708,130 has been shown to be an effective emitter for a blue light emitting diode (LED) (Grice, et.al, Applied Physics Letters, Vol. 73, 1998, p. 629-631) and to exhibit high carrier mobility, a very desirable feature for electronic devices (Redecker, et. al., Applied Physics Letters, Vol. 73, 1998, p. 1565-1567.

A means to further modify their optical and electronic properties is desired in order to broaden the applicability of these fluorene polymers in electronic devices. In this context, optical properties of a polymer include its absorption and photoluminescence spectra and electronic properties include ionization potential, electron affinity, band gap and carrier transport and mobility. U.S. Patent Application Serial Number 08/861,469, filed May 21, 1997, teaches a way for property modification via fluorene copolymers each containing 9,9-disubstituted fluorene and another comonomer. For instance, copolymers comprising fluorene and aromatic amines have lower (closer to vacuum level) ionization potential and preferential hole transporting properties, and copolymers with cyano-containing moieties have higher electron affinity and preferential electron transporting properties relative to fluorene homopolymers.

Many electronic applications require the active material to exhibit both hole transporting and electron transporting properties. To maximize the efficiency of a LED, for example, the polymer should ideally transport both holes and electrons equally well

(Bradley et. al., in Springer Series in Solid State Sciences, Vol 107, Springer-Verlag Berlin Heidelberg, 1992, p. 304-309). The copolymers of United States Patent Application Serial Number 08/861,469 filed May 21, 1997, comprising a fluorene moiety and one other comonomer cannot meet this requirement; therefore, there is a need for

5   further improvement.

This invention relates to copolymers of 9-substituted and/or 9,9-disubstituted fluorene moieties and at least two other comonomers containing delocalized p-electrons. Preferably, at least 10 percent of the total monomeric units of these copolymers are selected from 9-substituted- and/or 9,9-disubstituted fluorenes; more preferably at least

10   15 percent of the monomeric units of these copolymers are selected from 9-substituted- and/or 9,9-disubstituted fluorenes; and most preferably at least 20 percent of the monomeric units of these copolymers are selected from 9-substituted- and/or 9,9- disubstituted fluorenes. Each copolymer contains two or more non-fluorene comonomers in any proportion. These copolymers are characterized by their excellent solubility (>1

15   g/L) in common organic solvents, ability to form pin-hole free films and weight-average molecular weight of at least 3000 gram/mole relative to polystyrene standard, preferably at least 10,000 gram/mole, most preferably at least 20,000 gram/mole. They are further characterized by a polydispersity of less than 10, preferably less than 5, most preferably less than 3. These copolymers exhibit photoluminescent emission in the range of 350

20   nm to 1,000 nm and absorption from 200 nm to 600 nm. The copolymers of this invention are useful as the active components in electronic devices including light emitting diodes, photocells, photoconductors, and field effect transistors.

This invention relates to fluorene copolymers and electronic devices comprising a film of such copolymers. The subject copolymers comprise at least 10 percent, based on

25   residual monomeric units (RMU), of 9-substituted and/or 9,9-disubstituted fluorene moieties represented by structures I and II respectively. A residual monomeric unit is the portion of the monomer that is incorporated into the polymer backbone. For instance, 1,4-phenylene is the residual monomeric unit of 1,4-difunctional-benzene monomers irrespective of the chemical nature of the functional groups.
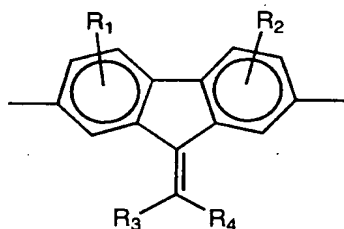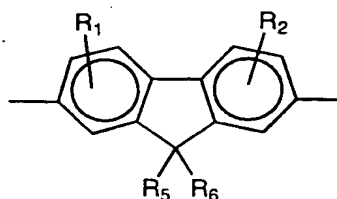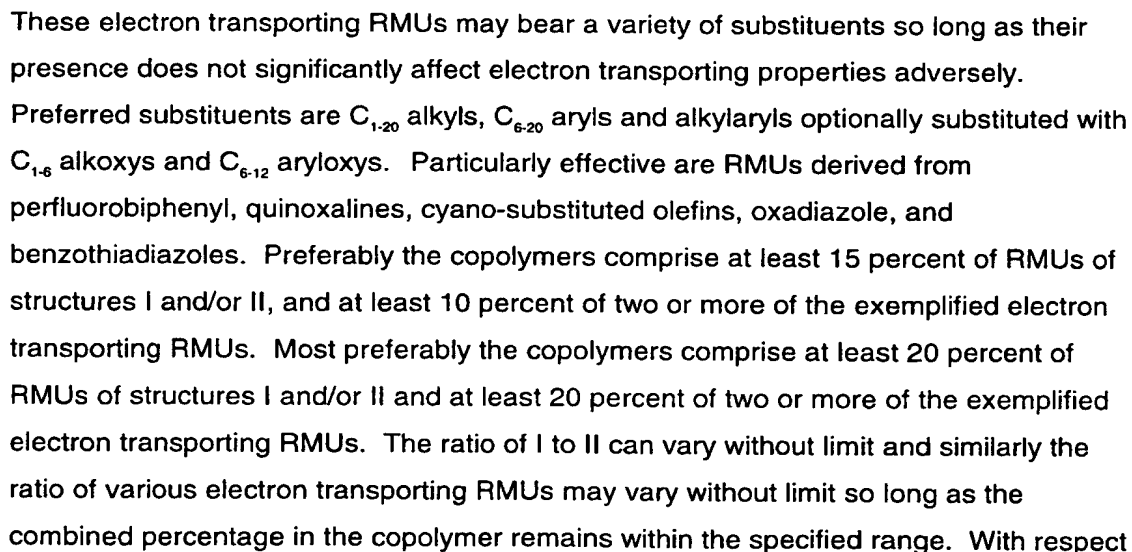
I   II

In structures I and II, R_1 and R_2 are independently in each occurrence hydrogen, C_{1-20} hydrocarbyl, C_{1-20} hydrocarbyloxy, C_{1-20} thiohydrocarbyloxy, or cyano. R_1 and R_2 are independently in each occurrence preferably hydrogen, C_{1-20} alkyl, C_{6-10} aryl or alkyl-substituted aryl, C_{6-10} aryloxy or alkyl-substituted aryloxy, C_{1-12} alkoxy/thioalkoxy, and cyano. Even more preferably R_1 and R_2 are independently in each occurrence hydrogen, C_{1-10} alkyl, phenyl, and cyano. R_3 and R_4 are independently in each occurrence a hydrogen, C_{1-20} hydrocarby optionally substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters; C_{6-20} aryl optionally substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters. R_3 and R_4 may also form C_{3-12} cyclic structures with the olefin carbon (structure I) to which they are attached, said cyclic structures may further contain one or more heteroatoms such as phosphorus, sulfur, oxygen and nitrogen. Preferably R_3 and R_4 are independently in each occurrence a hydrogen, C_{1-12} alkyl optionally substituted with C_{1-12} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano and esters; C_{6-20} aryl optionally substituted with C_{1-12} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters. Most preferably R_3 and R_4 are independently in each occurrence a hydrogen, C_{1-8} alkyl optionally substituted with C_{1-10} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters; C_{6-12} aryl optionally substituted with C_{1-10} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters. R_5 and R_6 are independently in each occurrence a hydrogen, C_{1-20} hydrocarby optionally substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters; C_{6-20} aryl optionally substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters. R_5 and R_6 may also form C_{3-12} cyclic structures with the C-9 carbon of

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fluorene (structure II), said cyclic structures may further contain one or more heteroatoms such as phosphorus, sulfur, oxygen and nitrogen. Preferably R_5 and R_6 are independently in each occurrence a hydrogen, C_{1-12} alkyl optionally substituted with C_{1-12} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy,

5   carboxylic/sulfonic acids, cyano and esters; C_{6-20} aryl optionally substituted with C_{1-12} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters. Most preferably R_5 and R_6 are independently in each occurrence a hydrogen, C_{1-8} alkyl optionally substituted with C_{1-10} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy,

10   carboxylic/sulfonic acids, cyano, and esters; C_{6-12} aryl optionally substituted with C_{1-10} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters. These copolymers are characterized by their excellent solubility (>1 g/L) in common organic solvents, ability to form pin-hole free films and weight-average molecular weight of at least 3,000 gram/mole relative to

15   polystyrene standard, preferably at least 10,000 gram/mole, most preferably at least 20,000 gram/mole. They are further characterized by a polydispersity of less than 10, preferably less than 5, most preferably less than 3. These copolymers exhibit photoluminescent emission in the range of 350 nm to 1,000 nm and absorption from 200 nm to 600 nm. The copolymers of this invention are useful as the active components in

20   electronic devices including light emitting diodes, photocells, photoconductors, and field effect transistors.

In the first embodiment, the copolymers of the invention comprise at least 10 percent RMU of structures I and/or II and at least 1 percent of two or more RMUs possessing hole transporting property. Hole transporting property is imparted to a

25   polymer by electron-rich RMUs. Examples include those derived from stilbenes or 1,4-dienes without electron-withdrawing substituents, tertiary amines, N,N,N',N'-tetraaryl-1,4-diaminobenzene, N,N,N',N'-tetraarylbenzidine, N-substituted-carbazoles, diarylsilanes, and thiophenes/furans/pyrroles without electron-withdrawing substitutents. These hole transporting RMUs may bear a variety of substituents so long as their presence do not

30   significantly affect hole transporting properties adversely. Preferred substituents are C_{1-20} alkyls, C_{6-20} aryls and alkylaryls optionally substituted with C_{1-6} alkoxys and C_{6-12} aryloxys. Particularly effective are RMUs derived from tertiary aromatic amines, N,N,N',N'-tetraaryl-1,4-diaminobenzene N,N,N',N'-tetraarylbenzidine, thiophene, and bithiophene. Preferably the copolymers comprise at least 15 percent of RMUs of structures I and/or II,

and at least 10 percent of two or more hole transporting RMUs. Most preferably the copolymers comprise at least 20 percent of RMUs of structures I and/or II and at least 20 percent of two or more RMUs possessing hole transporting property. The ratio of I to II may vary without limit and similarly the ratio of various hole transporting RMUs can vary

5   without limit so long as the combined percentage in the copolymer remains within the specified range. With respect to the hole transporting RMUs in the copolymers of the invention, there is no restriction that they must all belong to the same chemical type. A copolymer of the invention may, for example, contain RMUs of the silanyl type, RMUs of the thiophene type and RMUs of the tertiary amine type.

10   In the second embodiment the copolymers of the invention comprise at least 10 percent of RMUs of structures I and II and at least 1 percent of two or more RMUs possessing electron transporting property. Electron transporting property is imparted to polymers by electron-deficient RMUs. Examples include RMUs containing electron-withdrawing groups such as F, cyano, sulfonyl, carbonyl, nitro, carboxy; moieties

15   containing imine linkage, and condensed polycyclic aromatics. Condensed polycyclic aromatics include acenaphthene, phenanthrene, anthracene, fluoranthene, pyrene, perylene, rubrene, chrysene, and corene. Five-membered heterocylces containing imine linkages include oxazoles/isoxazoles, N-substituted-imidazoles/pyrazoles, thiazole/isothiazole, oxadiazoles, and N-substituted-triazoles. Six-membered

20   heterocycles containing imine linkages include pyridines, pyridazines, pyrimidines, pyrazines, triazines, and tetrazenes. Benzo-fused heterocycles containing imine linkages include benzoxazoles, benzothiazole, benzimidazoles, quinoline, isoquinolines, cinnolines, quinazolines, quinoxalines, phthalazines, benzothiadiazoles, benzotriazines, phenazines, phenanthridines, and, acridines. More complex RMUs include 1,4-

25   tetrafluorophenylene, 1,4'-octafluorobiphenylene, 1,4-cyanophenylene, 1,4-dicyanophenylene, and

X = O, S   X = O, S   X = O, S

These electron transporting RMUs may bear a variety of substituents so long as their presence does not significantly affect electron transporting properties adversely. Preferred substituents are C_{1-20} alkyls, C_{6-20} aryls and alkylaryls optionally substituted with C_{1-6} alkoxys and C_{6-12} aryloxys. Particularly effective are RMUs derived from perfluorobiphenyl, quinoxalines, cyano-substituted olefins, oxadiazole, and benzothiadiazoles. Preferably the copolymers comprise at least 15 percent of RMUs of structures I and/or II, and at least 10 percent of two or more of the exemplified electron transporting RMUs. Most preferably the copolymers comprise at least 20 percent of RMUs of structures I and/or II and at least 20 percent of two or more of the exemplified electron transporting RMUs. The ratio of I to II can vary without limit and similarly the ratio of various electron transporting RMUs may vary without limit so long as the combined percentage in the copolymer remains within the specified range. With respect

to the electron transporting RMUs in the copolymers of the invention, there is no restriction that they must all belong to the same chemical type. A copolymer of the invention may, for example, contain RMUs of the cyano-olefin type, RMUs of the oxadiazole type and RMUs of the condensed polynuclear aromatic type.

5   In the third embodiment, copolymers of the invention comprise at least 10 percent of RMUs of structures I and/or II and at least 1 percent of one or more hole transporting RMUs and at least 1 percent of one or more electron-transporting RMUs. Hole transporting RMUs and electron transporting RMUs are selected from among those already defined above. More preferably copolymers of this embodiment comprise at

10   least 15 percent of RMUs of structures I and/or II and at least 5 percent of one or more hole transporting RMUs and at least 5 percent of one or more electron-transporting RMUs. Most preferably copolymers of this embodiment comprise at least 20 percent of RMUs of structures I and/or II and at least 10 percent of one or more hole transporting RMUs and at least 10 percent of one or more electron-transporting RMUs. The ratio of I

15   to II can vary without limit and similarly the ratio of various hole transporting RMUs may vary without limit so long as the combined percentage in the copolymer remains within the specified range. With respect to the hole transporting RMUs in the copolymers of the invention, there is no restriction that they must all belong to the same chemical type. A copolymer of the invention may, for example, contain RMUs of the silanyl type, RMUs of

20   the thiophene type and RMUs of the tertiary amine type. Similarly, with respect to the electron transporting RMUs in the copolymers of the invention, there is no restriction that they must all belong to the same chemical type. A copolymer of the invention may, for example, contain RMUs of the cyano-olefin type, RMUs of the oxadiazole type and RMUs of the condensed polynuclear aromatic type.

25   In the fourth embodiment, copolymers of the invention comprise at least 10 percent of RMUs of structures I and/or II, at least 1 percent of one or more RMUs derived independently in each occurrence from benzene, naphthalene, and biphenylene optionally substituted with C_{1-12} alkyl/alkoxy and C_{6-10} aryl/aryloxy (hereinafter referred to as arylene RMUs), and at least 1 percent of one or more RMUs selected from among the

30   hole transporting and electron transporting RMUs defined above. Preferably copolymers of this embodiment comprise at least 15 percent of RMUs of structures I and/or II, at least 5 percent of one or more arylene RMUs, and at least 1 percent of one or more RMUs selected from among the hole transporting and electron transporting RMUs defined above. Most preferably copolymers of this embodiment comprise at least 20

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percent of RMUs of structures I and/or II, at least 10 percent of one or more arylene RMUs, and at least 5 percent of one or more RMUs selected from among the hole transporting and electron transporting RMUs defined above. The ratio of I to II can vary without limit and similarly the ratio of various arylene RMUs may vary without limit so long

5   as the combined percentage in the copolymer remains within the specified range. Incorporation of arylene RMUs can lead to modifications in the thermal, optical and electronic properties of the copolymers.

The fifth embodiment relates to blends of two or more of the copolymers of the invention without limits on relative proportions of the individual components. Such blends

10   may be prepared by solution blending, or blending in the melt state.

The sixth embodiment relates to blends containing at least 0.1 weight percent of at least one copolymer of the invention with at least one of the fluorene homopolymers or copolymers disclosed in US 5,708,130, US 5,777,070, and U.S. Application Serial No. 08/861,469. Such blends may be prepared by solution blending, or blending in the melt

15   state.

The seventh embodiment relates to blends containing at least 0.1 weight percent of at least one copolymer of the invention with at least one other non-fluorene polymer, for example, polystyrene, polyethylene, poly(methyl methacrylate), polysulfones, polycarbonates, and polyurethanes. Such blends may be prepared by solution blending,

20   or blending in the melt state.

The eighth embodiment relates to a film containing at least 0.1 weight percent of at least one copolymer of the invention.

The ninth embodiment of the invention relates to light emitting diodes comprising one or more of the copolymers of the invention wherein the copolymers are present as

25   single-layer films or as multiple-layer films, whose combined thickness is in the range of 10 nm to 1000 nm, preferably in the range of 25 nm to 500 nm, most preferably in the range of 50 nm to 300 nm. The copolymer films may be formed by solvent-based processing techniques such as spin-coating, roller-coating, dip-coating, spray-coating, and doctor-blading. When two or more copolymers are used, they may be deposited

30   separately as distinct layers or deposited as one layer from a solution containing a blend of the desired copolymers. An organic light emitting diode typically consists of an organic film sandwiched between an anode and a cathode, such that when a positive bias is applied to the device, holes are injected into the organic film from the anode and

electrons are injected into the organic film from the cathode. The combination of a hole and an electron may give rise to an exciton which may undergo radiative decay to the ground state by releasing a photon. The anode and the cathode may be made of any materials and in any structure known in the art. The anode is preferably transparent. A

5   mixed oxide of tin and indium (ITO) is useful as the anode due to its conductivity and transparency. ITO is deposited on a transparent substrate such as glass or plastic so that the light emitted by the organic film may be observed. The organic film may be the composite of several individual layers or may be the blend of several materials each designed for a specific function. The cathode is commonly a metallic film deposited on

10   the surface of the organic film by either evaporation or sputtering.

The tenth embodiment of the invention relates to photocells comprising one or more of the copolymers of the invention wherein the copolymers are present as single-layer films or as multiple-layer films, whose combined thickness is in the range of 10 nm to 1000 nm, preferably in the range of 25 nm to 500 nm, most preferably in the range of

15   50 nm to 300 nm. The copolymer films may be formed by solvent-based processing techniques such as spin-coating, roller-coating, dip-coating, spray-coating and doctor-blading. When two or more copolymers are used, they may be deposited separately as distinct layers or deposited as one layer from a solution containing a blend of the desired copolymers. By photocells is meant a class of optoelectronic devices which can convert

20   incident light energy into electrical energy. Examples of photocells are photovoltaic devices, solar cells, photodiodes, and photodetectors. A photocell generally comprises a transparent or semi-transparent first electrode deposited on a transparent substrate. A polymer film is then formed onto the first electrode which is, in turn, coated by a second electrode. Incident light transmitted through the substrate and the first electrode is

25   converted by the polymer film into excitons which can dissociate into electrons and holes under the appropriate circumstances, thus generating an electric current.

The eleventh embodiment of the invention relates to metal-insulator-semiconductor field effect transistors comprising one or more of the copolymers of the invention (serving as the semiconducting polymer) deposited onto an insulator wherein

30   the copolymers are present as single-layer films or as multiple-layer films whose combined thickness is in the range of 10 nm to 1000 nm, preferably in the range of 25 nm to 500 nm, most preferably in the range of 50 nm to 300 nm. The copolymer films may be formed by solvent-based processing techniques such as spin-coating, roller-coating, dip-coating, spray-coating and doctor-blading. When two or more copolymers are used,

they may be deposited separately as distinct layers or deposited as one layer from a solution containing a blend of the desired copolymers. Two electrodes (source and drain) are attached to the semiconducting polymer and a third electrode (gate) onto the opposite surface of the insulator. If the semiconducting polymer is hole transporting (that

5   is, the majority carriers are positive holes), then applying a negative DC voltage to the gate electrode induces an accumulation of holes near the polymer-insulator interface, creating a conduction channel through which electric current can flow between the source and the drain. The transistor is in the "on" state. Reversing the gate voltage causes a depletion of holes in the accumulation zone and cessation of current. The transistor is in

10   the "off" state. If the semiconducting polymer is electron transporting (that is, the majority carriers are electrons), then applying a positive DC voltage to the gate electrode induces a deficiency of holes (accumulation of electrons) near the polymer-insulator interface, creating a conduction channel through which electric current can flow between the source and the drain.

15   The copolymers of instant invention may be prepared by a variety of polycondensation processes. Particularly effective are those processes involving coupling of aromatic/vinylic/acetylenic monomers catalyzed by transition metals such as nickel and palladium.

          Coupling of aryl and vinyl halides with zerovalent nickel was reported by
20   Semmelhack et. al., (J. Am. Chem. Soc., Vol. 103, 1981, p. 6460-6471) . Coupling of aryl halides and other heteroaromatic halides with zerovalent nickel was discussed by Yamamoto et. al., (Macromolecules, Vol. 25, 1992, p. 1214-1223). These procedures require a large excess of the air and moisture sensitive zerovalent nickel. A variant that requires a truly catalytic amount of nickel but a large excess of zinc as the reducing agent

25   was first reported by Colon et. al., (J. Polym. Sci., Polym. Chem., Vol. 28, 1990, p. 367-383), and later applied successfully to fully conjugated polymers by Ueda et. al., (Macromolecules, Vol. 24, 1991, p. 2694-2697), represents an improvement with respect to experimental handling. In these procedures, mixtures of monomers each bearing two halogen substituents (preferably bromine and chlorine) can be polymerized into

30   copolymers of essentially random nature if the monomers are of about the same reactivity. If reactivities are significantly different, then the more reactive monomers would be polymerized preferentially over the less reactive ones. The result would be a somewhat "blocky" copolymer of uncertain structure and order. An additional disadvantage of these procedures is the presence of large amounts of metallic reagents

which must often be thoroughly removed from the resulting copolymers to avoid the deleterious effects they can have on electronic device performance.

Coupling reactions catalyzed by palladium are usually more preferred as the amount of palladium required is truly catalytic and the structure and order of the resulting copolymers are more predictable. Chen et. al., (Macromolecules, Vol. 26, 1993, p. 3462-3463), produced regiospecific polythiophenes by palladium catalyzed coupling of 2-bromo-5-(bromozinco)alkylthiophenes. The obtained molecular weights were very low, however. Coupling of aryl halides with acetylenes catalyzed by palladium was successfully used for producing copolymers by Yamamoto et. al., (Macromolecules, Vol. 27, 1994, p. 6620-6626), and coupling of aryl halides with olefins similarly employed for polymerization by Greiner et. al., (Macromol. Chem. Phys., Vol. 197, 1996, p. 113-134).

A preferred condensation reaction involves the coupling of organoboron compounds with organohalides as taught by Miyaura and Suzuki (Chemical Reviews, Vol. 95, 1995, p. 2457-2483). This reaction has been adapted with improvement to the production of high molecular weight polymers by Inbasekaran et. al., as reported in U.S. Patent 5,777,070. Polymerization is effected by reacting a near equimolar mixture of an aromatic/vinylic diboronic acid/ester (hereinafter referred to as type A monomer) and an aromatic/vinylic dibromide (hereinafter referred to as type B monomer). Two or more type A monomers and two or more type B monomers may be used so long as the combine molar amounts of A's are approximately equal to that of B's. A unique feature of copolymers from this process is the order which results from the fact that chain growth takes place exclusively via the formation of A-B dyads as each type A monomer can only react with a type B monomer. Monomers of more complex structures may be advantageously employed to yield copolymers of even higher degree of structural order. For example, an appropriately functionalized electron transporting RMU may be reacted with two molecules of a hole transporting moiety to yield a new monomer of the structure Br-HTRMU-ETRMU-HTRMU-Br, where HTRMU sand ETRMU stand for hole transporting RMU and electron transporting RMU respectively.

The following specific embodiments are given to illustrate the invention and should not be interpreted as limiting in any way.
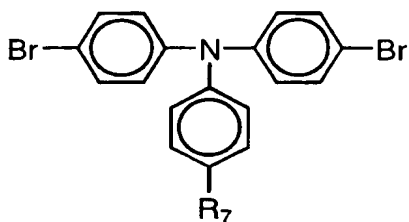
All inherent viscosity measurements were determined on THF solutions (0.5 g/dL) at 25°C and are expressed in unit of dL/gram. The formulas of the monomers used are given below.
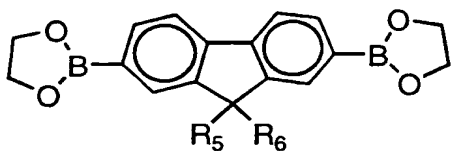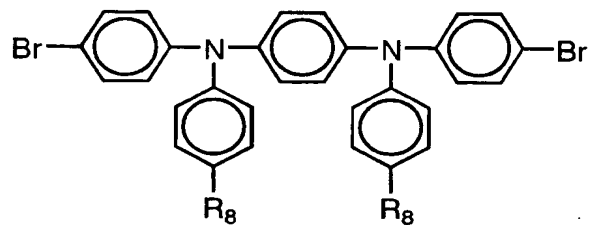
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1b, $R_5 = R_6 =$ n-hexyl
1c, $R_5 = R_6 =$ n-octyl
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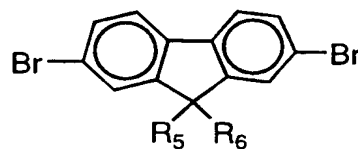
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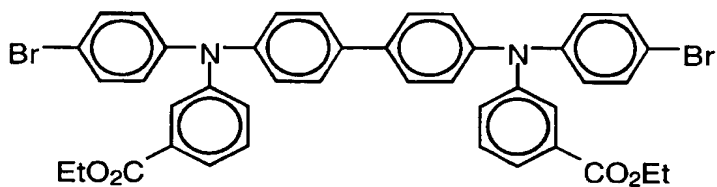
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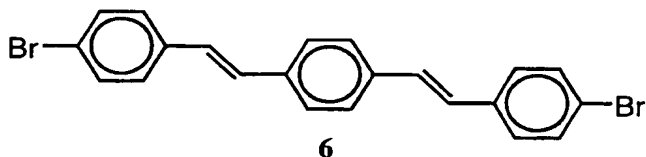
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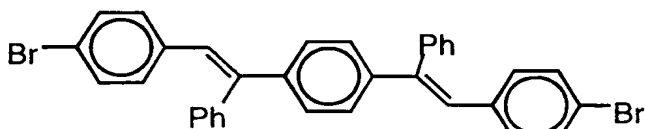
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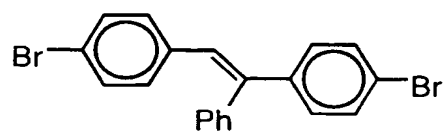
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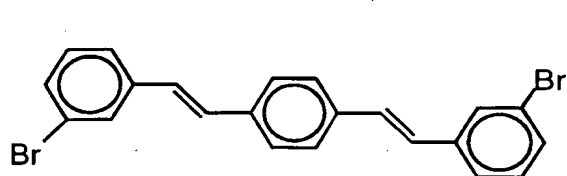
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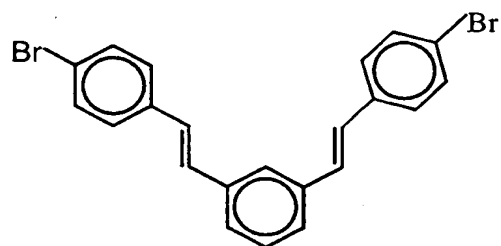
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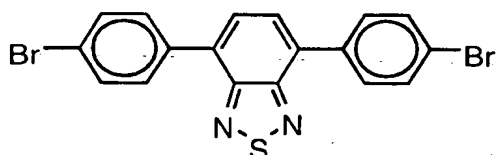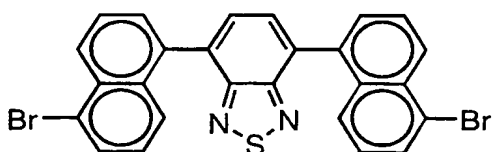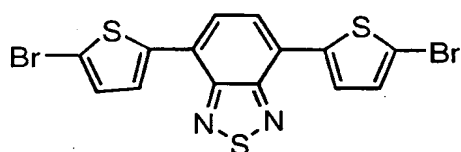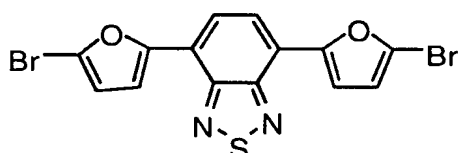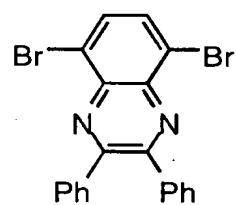
Monomers 2-5 and 11 are known compounds (see WO 97/33193 and U.S. Patent 5,777,070), and monomer 20 is commercially available. Procedures for the preparation of other monomers used in the following examples are given below. All compounds exhibit spectral data consistent with their structures.

General Procedure for the Preparation of 9,9-Disubstituted 2,7-Fluorene Diboronates (1)

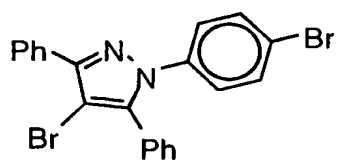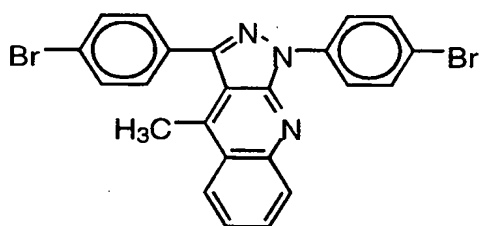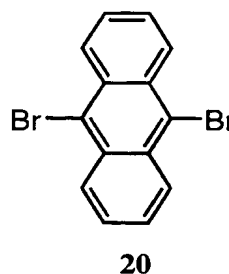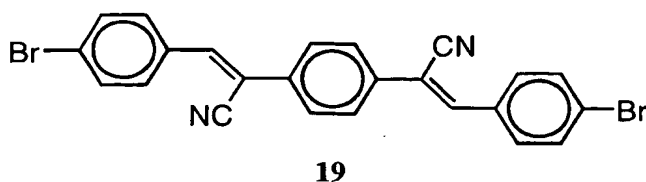To a stirred mixture of 9,9-disubstituted 2,7-dibromofluorene (10 mmol) and 50 mL of tetrahydrofuran (THF) under nitrogen at -78°C was added dropwise a 2.5 M solution of n-butyllithium in hexanes (8 mL, 20 mmol) over 10 min. The di-lithio intermediate precipitated in a few minutes and the resulting colorless suspension was stirred at -78 C for 1 hr. Tri-isopropylborate (7.5 g, 40 mmol) was added all at once, and the resulting slurry (additional 20-30 mL of THF added to facilitate agitation, in some cases) was stirred for 1 hr at -78° , 16 hours at room temperature, and poured into 300 mL of ice-water containing 25 mL of conc. HCl. After stirring for 30 min, the product was extracted with 2x150 mL of diethyl ether. The ether extracts were washed with saturated aqueous sodium chloride solution (200 mL), dried (MgSO$_4$) and rotary evaporated to remove the solvent providing the diboronic acid as a semi-solid. The purity of the crude diboronic acid was assessed to be 85-95 percent depending upon the substrate by HPLC analysis and was converted to the diboronate without further purification, as described below.

The crude diboronic acid was suspended in 50 mL of toluene and 30 mmol (1.86 g) of ethylene glycol, and the mixture was stirred and refluxed under a Dean-Stark trap for 2-3 hr. During this time, about 25 mL of toluene was collected as over-head along with a small amount of water formed during the reaction as an azeotrope. The reaction mixture was cooled and the solvent was removed. The residue (semi-solid) was recrystallized from hexane or toluene-hexane mixture, depending upon the substrate, to provide the diboronate as colorless, amorphous powder in 70-85 percent overall yield.

The purity, as judged by HPLC, was about 95-99 percent. Further recrystallization provided material of 99+ percent purity.

4,4'-Dibromo-1,4-distyrylbenzene (6)

To a stirred mixture of p-xylylenebis-(triphenylphosphonium bromide) (8.05 g, 10 mmol) and 4-bromobenzaldehyde (3.75 g, 20 mmol) in ethanol (100 mL) under nitrogen was added dropwise a solution of lithium ethoxide (1.0 M in ethanol, 21.5 mL, 21.5 mmol). The reaction was stirred at ambient temperature for 6 hours. The precipitate was filtered, washed with ethanol and dried. The crude product was redissolved in toluene, washed successively with aqueous hydrochloric acid (5 percent) and water and dried with magnesium sulfate. The solvent was evaporated under vacuum and the residue was recrystallized from toluene/methanol to afford 3.6 g (82 percent) of white solid. NMR indicated a trans-trans structure and the purity was found to be 100 percent as shown by HPLC·

4,4',-Dibromo-b,b'-diphenyl-1,4-distyrylbenzene (7)

To a stirred mixture of tetraethyl-o-xylylenediphosphonate (9.4 g, 25.0 mmol) and 4-bromobenzophenone (13.1 g, 50.0 mmol) in toluene was added potassium tert-butoxide (6.2 g. 55.0 mmol). The reaction was stirred at ambient temperature for 6 hours. The solution was filtered through a layer of celite. The solvent was evaporated under vacuum and the residue was recrystallized from toluene/hexane to give 5.8 g (39 percent) of light yellow solid material which was found to be a 1:4 mixture of the cis-trans and trans-trans isomers by HPLC.

1,2-Bis(4-bromophenyl)-1-phenylethylene (8)

To a stirred solution of 4-bromobenzophenone (5.22 g, 20 mmol) and diethyl-4-bromophenylphosphonate (6.8 g, 22 mmol) in 1,2-dimethoxyethane (60 mL) under nitrogen was added sodium hydride (0.52 g, 22 mmol) and the mixture was stirred and refluxed for 3 hours. After cooling, the mixture was poured into 150 g of ice water, the product was extracted with ether and purified by chromotography on silica gel. Elution with hexanes gave 6 grams (64 percent yield) of the title compound as a colorless oil which was found to be a 1:1 mixture of the cis and trans isomers.

3,3'-Dibromo-1,4-distyrylbenzene (9)

To a stirred mixture of p-xylylenebis-(triphenylphosphonium bromide) (15.8 g, 20 mmol) and 3-bromobenzaldehyde (7.4 g, 40.0 mmol) in ethanol (150 mL) under nitrogen

was added dropwise a solution of lithium ethoxide (1.0 M in ethanol, 41.0 mL, 41.0 mmol). The reaction was stirred at ambient temperature for 8 hours. The precipitate was filtered, washed with ethanol and dried. The crude product was redissolved in toluene, washed successively with aqueous hydrochloric acid (5 percent) and water and dried with

5   magnesium sulfate. The solvent was evaporated under vacuum and the residue was recrystallized from toluene/ethanol to afford 4.9 g (56 percent) of off-white solid. The purity was found to be >99 percent as shown by HPLC·

<u>4,4'-Dibromo-1,3-distyrylbenzene (10)</u>

To a stirred mixture of m-xylylenebis-(triphenylphosphonium bromide) (15.8 g, 20

10   mmol) and 4-bromobenzaldehyde (7.4 g, 40.0 mmol) in ethanol (200 mL) under nitrogen was added dropwise a solution of lithium ethoxide (1.0 M in ethanol, 41.0 mL, 41.0 mmol). The reaction was stirred at ambient temperature for 8 hours. The precipitate was filtered, washed with ethanol and dried. The crude product was redissolved in toluene, washed successively with aqueous hydrochloric acid (5 percent) and water and dried with

15   magnesium sulfate. The solvent was evaporated under vacuum and the residue was recrystallized from toluene/ethanol to afford 3.8 g (43 percent) of yellow flakes which was found to be >99 percent in purity as shown by HPLC.

<u>2,5-Di(4-bromophenyl)-2,1,3-benzothiadiazole (12)</u>

A mixture of phenylboronic acid (17.6 g, 144.0 mmole), 4,7-dibromo-2,1,3-

20   benzothiadiazole (21.0 g, 71.4 mmole), tetrakis(triphenylphosphine) palladium (180 mg, 0.156 mmol), Aliquat 336 (1.5 g), aqueous sodium carbonate (2 M, 100 mL) toluene (350 mL) was stirred and refluxed for 14 h under nitrogen. After cooling, the aqueous layer was separated, the organic layer was washed with water and dried. The solvent was removed and the residue was crystallized from toluene-ethanol give 11.4 g (55 percent)

25   of the crystalline material.

To a stirred solution of above 2,5-diphenyl-2,1,3-benzothiadiazole (7.0 g, 30.6 mmol) in acetic acid (50 mL) was added dropwise bromine (13.7 g, 77.5 mmol). The reaction was stirred and refluxed for 8 hours. After cooling water (100 mL) was added and the reaction was allowed to stand at ambient temperature for 2 hours. The product

30   was filtered, washed with water and dried. Recrystallized from toluene/ethanol afforded 9.3 g (68 percent) of yellow powder. The purity was found to be >98 percent as shown by NMR and HPLC·

2,5-Di(4-bromonaphthyl)-2,1,3-benzothiadiazole (13)

To a stirred solution of 2,5-dinaphthalenyl-2,1,3-benzothiadiazole [Prepared from naphthylboronic acid and 4,7-dibromo-2,1,3-benzothiadiazole by the procedure described in (12) for the preparation of 2,5-diphenyl-2,1,3-benzothiadiazole] (9.9 g, 25.5 mmol) in 1,4-dioxane (80 mL) was added dropwise bromine (12.4 g, 77.5 mmol). The reaction was stirred and refluxed for 6 hours. After cooling ethanol (100 mL) was added and the reaction was allowed to stand at ambient temperature for 10 hours. The product was filtered and washed with ethanol. Recrystallized from toluene/ethanol gave 9.2 g (66 percent) of yellow flakes. The purity was found to be >95 percent as shown by NMR and HPLC·

4,7-Bis (5-bromo-2-thienyl)-2,1,3-benzothiadiazole (14)

4,7-Dithien-2-yl-2,1,3-benzothiadiazole [prepared by reacting 4,7-dibromo-2,1,3-benzothiadiazole with tributyl(thien-2-yl)stannane by following published procedure (Kitamura et al., Chem. Mater., Vol. 8, 1996, p. 570-578)] (7.7 g, 25.7 mmol) was dissolved in a mixture of chloroform (200 mL) and acetic acid (200 mL) under nitrogen and N-bromosuccinimide (9.61 g, 54 mmol) was added all at once. After stirring the reaction mixture at RT all night, the dark red precipitate was filtered off and recrystallized from DMF twice to provide the title compound as shiny, red crystals (6.85 g, 58.2 percent) which had a purity of 100 percent as shown by HPLC analysis.

2,5-Di(5'-bromofuranyl)-2,1,3-benzothiadiazole (15)

To a stirred solution of 2,5-difuranyl-2,1,3-benzothiadiazole [prepared by reacting 4,7-dibromo-2,1,3-benzothiadiazole with 2-(tributylstannyl)furan by following published procedure (Kitamura et al., Chem. Mater., Vol. 8, 1996, p. 570-578)](2.9 g, 10.1 mmol) in 1,4-dioxane (40 mL) was added dropwise bromine (3.6 g, 22.3 mmol). The reaction was stirred at ambient temperature for 5 minutes. The reaction was then diluted with water and the precipitate was filtered, washed with water and dried. The crude product was redissolved in toluene and chromatographed on a short alumina column. The solvent was evaporated under vacuum and the residue was recrystallized from toluene/ethanol to afford 3.0 g (70 percent) of red flakes which was found to be >99 percent in purity as shown by HPLC.

5,8-Dibromo-2,3-diphenylquinoxaline (16)

3,6-Dibromo-1,2-phenylenediamine (prepared by reduction of 4,7-dibromo-2,1,3-benzothiadiazole with zinc and acetic acid as reported by Naef and Balli (Helv. Chim.

5   Acta, 1978, 61, 2959) (2 g, 8 mmol) and benzil (1.9 g, 9 mmol) were dissolved in 2-propanol (40 mL) and 5 drops of trifluoroacetic acid was added. The mixture was stirred and heated under reflux for 2 hr. On cooling, the pale yellow solid was filtered and recrystallized from ethanol to give 2.7 g (75 percent) of the title compound as colorless solid, mp 221-223°C.

10   ### 4-Bromo-1-(4-bromophenyl)-3,5-diphenylpyrazole (17)

The title compound was obtained by the bromination of 1-(4-bromophenyl)-3,5-diphenylpyrazole (obtained by reacting dibenzoylmethane and 4-bromophenyl hydrazine in acetic acid) with N-bromosuccinimide in DMF at 65°C for 1 hr. The crude product was recrystallized from ethanol to provide the title compound as colorless powder in 72

15   percent yield and the purity was 100 percent as shown by HPLC.

1,3-Bis(4-bromophenyl)-4-methyl-1H-pyrazolo[3,4-b]quinoline (18)

A mixture of 1,3-bis(4-bromophenyl)-pyrazolin-5-one (7.9 g, 20 mmol) and o-aminoacetophenone (2.7 g, 20 mmol) in 30 mL of ethylene glycol was heated and stirred at 180°C under nitrogen for 22 hr. The dark red solution was cooled, 40 mL of ethanol

20   added, refluxed for 1 hr and cooled. The yellow solid was filtered and recrystallized from toluene-hexane to provide 2.3 g (26 percent yield) of the title compound as yellow crystals. The purity was found to be 100 percent as shown by HPLC.

a,a-Bis(4-bromophenylmethylene)-1,4-benzenediacetonitrile (19)

A mixture of 4-bromobenzaldehyde (24.0 g, 0.13 mole), phenylene-1,4-

25   diacetonitrile (10.0 g, 0.064 mole), piperidine (5 mL), and ethanol (150 mL) was refluxed for 3 h and the mixture allowed to stand overnight at room temperature. The orange crystalline solid was filtered and washed three times with ethanol (200 mL) and dried to give 15.3 g (50 percent) of the desired product. The ¹H nmr spectrum is consistent with the structure of the desired product. Recrystallization from DMF provided a very pure

30   product for polymerization.

The copolymers of the invention were prepared by the procedure of U.S. Patent 5,777,070 except those involving monomer 14 which required THF as a cosolvent. The

structures and monomeric reactants of the exemplified copolymers are given in Table 1; the properties of copolymers are given in Table 2.

Table 1. Compositions of Fluorene Copolymers.

Copolymer	Copolymer Empirical Formula [A]	Monomer (mmoles)	Monomer (mmoles)	Monomer (mmoles)	Monomer (mmoles)
1	$-[(1c)_{35}-(3a)_2-(4b)_3]_n-$	1c (10.2)	2c (7.5)	3a (1.0)	4b (1.5)
2	$-[(1c)_{20}-(11)_{17}-(20)_3]_n-$	1c (10.2)	11 (8.5)	20 (1.5)	
3	$-[(1c)_2-(11)_1-(3a)_1]_n-$	1c (8.2)	11 (4.0)	3a (4.0)	
4	$-[(1b)_3-(11)_2-(3a)_1]_n-$	1b (12.3)	11 (8.0)	3a (4.0)	
5	$-[(1b)_4-(11)_3-(3a)_1]_n-$	1b (12.3)	11 (9.0)	3a (3.0)	
6	$-[(1b)_3-(11)_1-(3b)_2]_n-$	1b (12.3)	11 (4.0)	3b (8.0)	
7	$-[(1b)_2-(12)_1-(3a)_1]_n-$	1b (10.2)	12 (5.0)	3a (5.0)	
8	$-[(1b)_2-(13)_1-(3a)_1]_n-$	1b (8.2)	13 (4.0)	3a (4.0)	
9	$-[(1b)_{34}-(5)_5-(11)_1]_n-$	1b (10.2)	2b (7.0)	5 (2.5)	11 (0.5)
10	$-[(1c)_2-(16)_1-(3a)_1]_n-$	1c (3.5)	16 (1.7)	3a (1.7)	
11	$-[(1c)_{10}-(2c)_5-(20)_3-(4b)_2]_n-$	1c (10.2)	2c (5.0)	20 (3.0)	4b (2.0)
12	$-[(1b)_{15}-(3a)_2-(20)_3]_n-$	1b (10.2)	2b (5.0)	3a (2.0)	20 (3.0)
13	$-[(1f)_3-(1c)_2-(19)_1]_n-$	1f (3.0)	2c (2.0)	19 (1.0)	
14	$-[(1c)_{19}-(19)_1]_n-$	1c (4.0)	2c (3.6)	19 (0.4)	
15	$-[(1c)_{39}-(19)_1]_n-$	1c (4.0)	2c (3.8)	19 (0.2)	
16	$-[(1f)_2-(1d)_1-(1e)_1-(19)_2]_n-$	1f (2.1)	1d (1.0)	2c (1.0)	19 (2.0)
17	$-[(1c)_1-(18)_1]_n-$	1c (4.1)	18 (4.0)		
18	$-[(1c)_{19}-(17)_1]_n-$	1c (8.2)	17 (8.0)		

Table 1. Continued. Compositions of Fluorene Copolymers.

Copolymer	Copolymer Empirical Formula [A]	Monomer (mmoles)	Monomer (mmoles)	Monomer (mmoles)	Monomer (mmoles)
19	$-[(1c)_{10}-(11)_9-(14)_1]_n-$	1c (8.2)	11 (7.2)	14 (0.8)	
20	$-[(1c)_4-(11)_3-(14)_1]_n-$	1c (5.2)	11 (3.8)	14 (1.2)	
21	$-[(1e)_2-(11)_1-(14)_1]_n-$	1e (2.6)	11 (1.3)	14 (1.3)	
22	$-[(1c)_{100}-(11)_{97}-(14)_3]_n-$	1c (8.2)	11 (7.8)	14 (0.2)	
23	$-[(1c)_{20}-(11)_{17}-(14)_3]_n-$	1c (6.2)	11 (5.1)	14 (0.9)	
24	$-[(1c)_7-(11)_2-(14)_1]_n-$	1c (5.1)	2b (2.0)	11 (2.0)	14 (1.0)
25	$-[(1c)_{10}-(11)_1-(15)_1]_n-$	1c (10.3)	15 (1.0)	11 (9.0)	
26	$-[(1c)_1-(8)_1]_n-$	1c (11.0)	8 (10.8)		
27	$-[(1c)_1-(6)_1]_n-$	1c (10.3)	6 (10.0)		
28	$-[(1d)_1-(6)_1]_n-$	1d (10.3)	6 (10.0)		
29	$-[(1c)_1-(10)_1]_n-$	1c (10.3)	10 (10.0)		
30	$-[(1c)_1-(9)_1]_n-$	1c (10.3)	9 (10.0)		
31	$-[(1c)_1-(7)_1]_n-$	1c (9.9)	7 (9.6)		
32	$-[(1c)_{10}-(2b)_7-(20)_3]_n-$	1c (10.2)	2c (7.0)	20 (3.0)	

[A] Bold type numerals in copolymer empirical formulas refer to RMUs of the corresponding monomers.

Table 2. Properties of Fluorene Copolymers.

Copolymer	T_g (°C)	Inherent Viscosity	Absorption[A] (nm)	Fluorescence[B] (nm)	Bandgap (eV)
1	-	1.50	383	467	
2	108	1.33	323 462	535	
3	100	1.27 [c]	346, 384 459	535	
4	108	0.95 [D]	339, 393 466	545	
5	125	1.18	320, 339 461	550	
6	140	0.52	336, 383 450	558	
7	195	3.00	352	544	
8	201	1.10	348 383	524	
9	136	1.70	381	531	
10	125	0.52	342 389	507	
11	81	1.00	388	480	
12	-	0.45	383	431	2.89
13	131	0.57	390	500	
14	108	0.78	390	510	2.62
15	97	0.85	390	510	2.71
16	102	0.94	420	515	2.52
17	-	0.95	355	497	
18	-	0.21	347	420 525	
19	120	1.82	322, 467 560	642	2.10
20	132	1.25	341, 474 550	639	
21	105	1.41	389, 460 570	659	
22	103	1.43	322 465	666	
23	125	1.24	320, 470 556	646	

Table 2. Continued. Properties of Fluorene Copolymers.

Copolymer	T_g (°C)	Inherent Viscosity	Absorption[A] (nm)	Fluorescence[B] (nm)	Bandgap (eV)
24	112	1.15	383, 463 550	639	
25	119	1.1	325 339	630	
26	82	0.31	375	441 470	
27	135	0.55	373	456 483	2.76
28	134	0.33	388	440 475	2.75
29	101	0.23	359	433	2.95
30	92	0.25	335	428	3.20
31	134	0.30	381	492	2.68
32	130	1.73	384	440	

[A] Absorption peaks of copolymer films

[B] Fluorescence peaks of copolymer films

[C] Weight-average molecular weight 97,000 by light scattering

[D] Weight-average molecular weight 53,000 by light

Light Emitting Diodes (LED)

ITO-coated glass with sheet resistance of about 15 ohms/square was used as substrate for diode fabrication. The ITO side of the substrate was treated with a 100 nm coating of Baytron P™ (a conducting polymer available from Bayer A.G.) diluted with either equal part or two parts of poly(styrenesulfonic acid). The conducting polymer film was dried at 200°C in air for about 5 minutes and was then coated with an light emitting polymer film by spin-coating with solutions of polymers in xylene. The light emitting polymer film was then dried in a nitrogen atmosphere at 90°C for at least two hours. Onto the light emitting polymer film was then deposited a calcium cathode (about 75 - 100 nm). The finished device was connected to a power source, in an inert atmosphere,

with ITO being the positive electrode. Luminance of emitted light and density of current flowing through the diode were monitored as a function of applied voltage. Luminance is expressed in unit of Cd/m^2, and efficiency expressed as lumens/watt (L/W): L/W = p (Cd/A)/V where A and V are respectively the current and voltage for a given brightness.

5   Green LEDs.

Table 3 lists the compositions and voltages and efficiency at 4000 Cd/m^2 of 3 green LEDs, two of which contain copolymers of the invention. Green 1 and Green 2, of approximately the same performance, reaching luminance of 4000 Cd/m^2 at lower voltage and higher efficiency than the comparative LED which does not contain

10   copolymer of the invention. The copolymer of the comparative example differs from copolymers 4 and 5 in the absence of a hole transporting RMU, thus illustrating the advantage of achieving a balance in hole and electron transport properties. Note the same benefit is realized in the blend (Green 2) containing a copolymer of the invention.

Table 3. Green LEDs

		4000 Cd/m^2	
Example	Copolymer Film : Structure [A]	Volts	L/W
Green 1	100 nm copolymer 5: -[(1b)$_4$-(11)$_3$-3a]-	3.9	2.36
Comparative	100 nm comparative copolymer: -[1b-11]-	6.3	0.56
Green 2	75 nm blend of 30 weight percent comparative copolymer in copolymer 4. Comparative copolymer: -[1b-11]- Copolymer 4: -[(1b)$_3$-(11)$_2$-3a]-	3.7	2.65

15   [A] Bold type numerals in copolymer empirical formulas refer to RMUs of the corresponding monomers.

Red LEDs.

Table 4 lists two LEDs that emit red light. Red 1 is based on a single copolymer while Red 2 is based on a blend of two copolymers of the invention. The marked

20   improvement in device performance noted in Red 2 over Red 1 demonstrates the advantages of using polymer blends.

23

Table 4. Red LEDs

Example	Copolymer Film : Structure [A]	1000 Cd/m^2	
		Volts	L/W
Red 1	75 nm copolymer 19: -[(1c)$_{10}$-(11)$_9$-14]-	9.0	0.12
Red 2	75 nm blend of 30 weight percent copolymer 19 in copolymer 5.	5.0	0.41

[A] Bold type numerals in copolymer empirical formulas refer to RMUs of the corresponding monomers.

White LED

5   Two white LEDs each based on a 100 nm film of a blend containing copolymer 22 of the invention in a mixture of fluorene copolymers not of this invention (hereinafter referred to as comparative mixture). The comparative mixture is a blend of

                15 weight percent of fluorene copolymer -[1c-4a]-

                7 weight percent of fluorene copolymer -[1c-3a]-

10   78 weight percent of fluorene homopolymer -[1c]-

The amount of copolymer 22 and LED performance are provided in Table 5. The comparative mixture without copolymer 22 is a blue light emitter and the addition of 1 weight percent or less of copolymer 22 of the invention converts the blend into a white light emitter. This example illustrates the impact an extremely small amount of a

15 copolymer of the invention can have on LEDs.

Table 5. White LEDs

Example	Copolymer of invention in blend [A]	1500 Cd/m^2	
		Volts	L/W
White 1	0.5 weight percent copolymer 22, -[(1c)$_{100}$-(14)$_3$]-, in blend	10.8	0.2
White 2	1.0 weight percent copolymer 22, -[(1c)$_{100}$-(14)$_3$]-, in blend	8.9	0.3

[A] Bold type numerals in copolymer empirical formulas refer to RMUs of the corresponding monomers.

CLAIMS:

1. A copolymer comprising monomeric units and further characterized by having

5   (a) at least 10 percent of the monomeric units are fluorene moieties selected from
9-substituted fluorene moieties, 9,9-disubstituted fluorene moeities or combinations
thereof; and

(b) at least 1 percent of the monomeric units comprising two other moieties which
are different from each other but which both comprise delocalized π-electrons; the other
10   moieties being independently selected from the group consisting of moities that have hole
transporting properties and moieties that have electron transporting properties; wherein
if both of the two other moieties have hole transporting properties, then at least one of
said moieties is derived from stilbenes or 1,4-dienes without electron withdrawing
substituents, N,N,N',N'-tetraarylbenzidines, N-substituted-carbazoles, diarylsilanes, and
15   thiophenes/furans/pyrroles without electron-withdrawing substituents.

2. The copolymer of Claim 1 wherein the fluorene moieties are selected from
groups having the formulas:

I   II
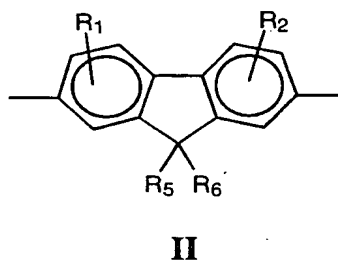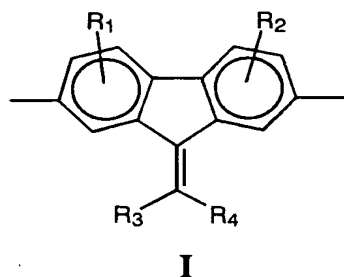
20   wherein, R_1 and R_2 are independently in each occurrence hydrogen, C_{1-20} hydrocarbyl, C_{1-20} hydrocarbyloxy, C_{1-20} thiohydrocarbyloxy, or cyano

R_3 and R_4 are independently in each occurrence a hydrogen, C_{1-20} hydrocarbyl
optionally substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary
amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters; C_{6-20} aryl optionally
25   substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines,
hydroxy, carboxylic/sulfonic acids, cyano, and esters; or R_3 and R_4 form C_{3-12} cyclic
structures with the olefin carbon to which they are attached, said cyclic structures
optionally further contain one or more heteroatoms such as phosphorus, sulfur, oxygen
and nitrogen;

R_5 and R_6 are independently in each occurrence a hydrogen, C_{1-20} hydrocarbyl optionally substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines, hydroxy, carboxylic/sulfonic acids, cyano, and esters; C_{6-20} aryl optionally substituted with C_{1-20} alkoxy/aryloxy, thioalkoxy/thioaryloxy, secondary/tertiary amines,

5   hydroxy, carboxylic/sulfonic acids, cyano, and esters; or R_5 and R_6 form C_{3-12} cyclic structures with the C-9 carbon of fluorene, said cyclic structures optionally further contain one or more heteroatoms such as phosphorus, sulfur, oxygen and nitrogen.

3. The copolymer of Claim 1 wherein at least 15 percent of the monomeric units

10   are the fluorene moieties and at least 10 percent of the monomeric units are two moeities which have hole transporting properties.

4. The copolymer of Claim 1 wherein at least 15 percent of the monomeric units are the fluorene moieties and at least 10 percent of the monomeric units are two moieties

15   which have electron transporting properties.

5. The copolymer of Claim 1 wherein the moieties having electron transporting properties are selected from moieties comprising electron-withdrawing groups.

20   6. The copolymer of Claim 1 wherein at least 1 percent of the monomeric units comprise hole transporting moieties and at least 1 percent of the monomeric units comprise electron transporting moeities.

7. The copolymer of Claim 6 wherein at least 15 percent of the monomeric units

25   are the fluorene moieties, at least 5 percent of the monomeric units have hole transporting properties, and at least 5 percent of the monomeric units have electron transporting properties.

8. A copolymer comprising monomeric units and further characterized in that

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(a) at least 10 percent of the monomeric units are fluorene moieties selected from 9-substituted fluorene moieties, 9,9-disubstituted fluorene moeities or combinations thereof; and

(b) at least 1 percent of the monomeric units are independently selected in each occurrence from the group consisting of moieties that have hole transporting properties and moieties that have electron transporting properties; and

(c) at least 1 percent of the monomeric units are derived from substituted or unsubstituted benzene, naphthalene, and biphenylene, wherein if a substituted compound is used the substituents are selected from alkyl or alkoxy groups having 1 to 12 carbon atoms and aryl or aryloxy groups having 6 to 10 carbon atoms.

9. A composition comprising a blend of a first polymer, which is selected from the copolymer of Claim 1 and the copolymer of Claim 8, with a second polymer.

10. The composition of Claim 9 wherein the second polymer comprises monomeric units selected from 9-substituted fluorene moeities, 9,9-disubstituted fluorene moieties, and combinations thereof.

11. The composition of Claim 9 wherein the second polymer is a copolymer as defined in Claim 1 and is different from the first polymer.

12. The composition of Claim 9 wherein the first polymer is present in an amount of at least 0.1 weight percent based on total weight of the composition.

13. A film comprising at least 0.1 percent by weight of a polymer selected from the copolymer of Claim 1 and the copolymer of Claim 8.

14. A light emitting diode comprising an anode, a cathode, and at least one film of Claim 13 located between the anode and the cathode.

15. The light emitting diode of Claim 14 wherein the anode comprises a mixed oxide of tin and indium and the cathode comprises a metallic film.

16. A photocell comprising at least one film of Claim 13.

17. The photocell of Claim 16, wherein the at least one film is located between a transparent or semi-transparent first electrode and a second electrode.

18. A metal-insulator-semiconductor field effect transistor comprising an insulating layer, at least one film of Claim 13 deposited onto that substrate, a source electrode connected to a first portion of the at least one film, a drain electrode connected to a second portion of the at least one film, and a gate electrode located on the opposite side of the insulating layer from the at least one film.

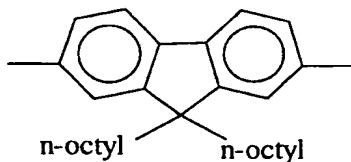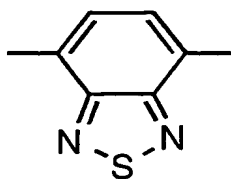19. A composition comprising a copolymer which comprises the following monomeric units:

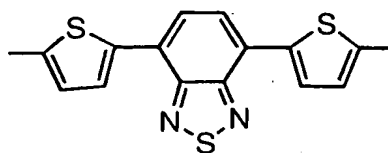n-hexyl   n-hexyl   ,

and

· sec-butyl
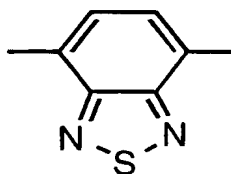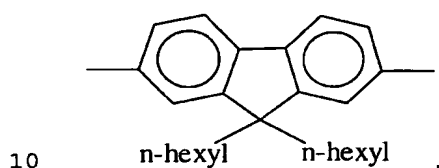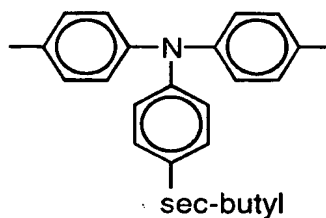
20. A light emitting diode comprising a film comprising the composition of Claim 19.

21. A composition comprising a copolymer having the following monomeric units:

n-octyl   n-octyl

and

22. A light emitting diode comprising a film comprising the composition of Claim
21.

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   C09K11/06   C08G61/10   H01L51/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   C09K   H01L   C08G   C08L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 777 070 A (INBASEKARAN MICHAEL ET AL) 7 July 1998 (1998-07-07) cited in the application column 3, line 50,51 examples 2,5	1-21
A	WO 97 05184 A (DOW CHEMICAL CO) 13 February 1997 (1997-02-13) example 28	1-21
A	FR 2 702 870 A (THOMSON CSF) 23 September 1994 (1994-09-23) figures 10A,10B	1,2
A	WO 97 33193 A (DOW CHEMICAL CO) 12 September 1997 (1997-09-12) page 10, line 19 - line 23	1,2

☐ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 September 1999	06/10/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Paalman, R

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Form PCT/ISA/210 (second sheet) (July 1992)

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